A Novel U-Shaped Tri-Band Antenna on High Permittivity Multilayer Substrate for Wireless Communications

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Abstract—In this paper, a detailed study of a new proposed rectangular dielectric u-shaped tri-band antenna is presented. A meticulous study considering the high permittivity material effect is introduced and discussed. All the design procedures are performed by using CST MS software. Moreover, the modified shaped patch antenna by introducing a slot on the rectangular radiated patch, offers improved bandwidth and allows an important miniaturization in size. Note that the proposed antenna can be used for several wireless technologies, especially for the GSM, Bluetooth, Wi-Fi, WLAN, WiMAX, all bands GPS frequencies, ISM band and ultra wide band applications. Detailed design steps, parametric studies and the simulation results for the proposed antenna are investigated under specific scenarios. Finally some concluding remarks will be drawn.

Index Terms—High permittivity, Multi-band and UWB patch antennas, bandwidth, miniaturization, wireless technologies.

1 INTRODUCTION

In the last few years, the microstrip technology are the most rapidly developing antennas. Several advantages that are the reasons that make it very attractive for consumer communications; it promises to revolutionize high data rate transmission and enables the personal area networking industry leading to new innovations and greater quality of service to end user. These antennas have a wide application in the field of mobile communications, integrated systems, satellites, and so forth. The microstrip antennas have many advantages, which are lightweight, small size, low cost, and ease of installation. One of the most important disadvantages of the microstrip antennas is their limited bandwidth, especially to cover a certain band of a specific application.

The explosive growth of wireless communication systems has led to an increasing demand for integrating a new shaped antenna with a compact low-cost RF front end [1,2]. Patch antennas have a planar structure, suitable for integration on a multilayered material, such as multilayer organic (MLO) or low temperature co-fired (LTCC) materials [2]. The LTCC multilayer technology is becoming more and more popular for its flexibility in realizing an arbitrary number of layers with easy-to-integrate circuit components like via-holes, thick film resistors [3], cavity-buried or top-mounted simultaneous multi-threading (SMT) components, or even chip devices. Typically, LTCC materials possess a high dielectric constant [4]. On one hand, this helps to miniaturize the antenna size due to the shorter wavelengths in such high dielectric-constant materials and the resonant nature of the patch radiator [5-9]. The principal aim of this article is to propose a suitable structure design of a compact multi-band antenna for 2G, 3G, 4G and UWB communication systems on high permittivity substrate [10,12,13]. As it will be demonstrate, to cover several mobile and wireless communication technologies, precisely GSM (890-960 MHz), DCS1800 (1710-1880 MHz), PCS 1900 (1850-1950 MHz), UMTS (1920-2170 MHz), IEEE 802.11b, Bluetooth and GPS Frequency band. The geometrical configuration of the new antenna, especially the dielectric permittivity [11], the thickness of the upper substrate, the partial ground plane and the position of the feed line; are the critical parameters which allow to obtain the desired operational bands,

2 ANTENNA STRUCTURE AND DESIGN GUIDELINES

2.1 Geometry of the Basic Antenna

As mentioned previously, our principal objective is focused on the development of a new tri-band antenna structure with a high permittivity multilayer dielectric substrate. The original idea of the proposed antenna originates from the simple rectangular antenna. To achieve our new antenna structure, firstly we concentrate our work to develop and optimize step by step the parameters of the simple rectangular antenna for the required band. The simple proposed antenna geometry under study is shown in Fig. 1. The antenna consists in a rectangular patch printed on the Gallium Arsenide substrate of

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permittivity 12.9 with loss tangent 0.006. The size of the substrate is (L_s x W_s x H_1) = (32 mm x 13 mm x 4 mm). The dimensions of feed line and the partial ground plane are 2.5 mm x 7.8 mm and 13 mm x 4 mm respectively. The feed line is excited by RF source with impedance of $50\,\Omega$. Then the antenna should be matched to characteristic impedance of microstrip line feed. As can be seen in Fig. 1-b-, the radiated element has been covered by a high dielectric permittivity. The rest parameter values to construct the basic antenna are as follows: W_p = 10 mm, L_p = 16

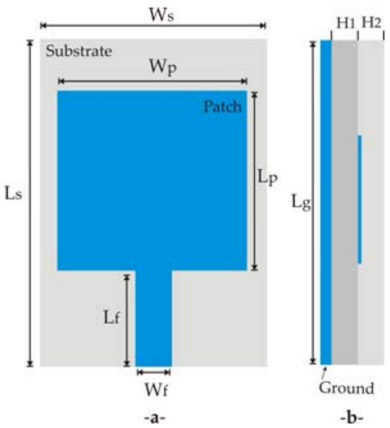


Fig. 1. Geometry of the compact proposed antenna under study.

mm, H_2 = 1 mm and the dielectric permittivity of the upper Substrate is 25.

It should be noted that, the upper substrate would have a big influence over the operating frequency band of the proposed antenna. Nevertheless, along with the high of the upper substrate, partial ground and the implementation of slots on the patch element, other parameters as the position of the feed line would be affect the desired operational bands.

2.2 Optimized Basic Antenna Parameters

It should be noted that, an optimization of the basic antenna parameters of the previous paragraph is necessary to obtain the best responses. Afterward a detailed analysis, the final basic antenna geometry parameters are fixed in the following values : W_p = 10 mm, L_p = 16.2 mm, H_2 = 0.8 mm, W_s = 32 mm, L_s = 13 mm, H_1 = 3.5 mm, W_f = 2.5 mm, L_f = 7.8 mm and L_g = 16.2 mm. Taken into account that, the dielectric permittivity of the upper Substrate is always 25. Nevertheless, the geometrical parameters which affect the antenna performance will be analyzed to drive some design rules.

A. Effect of the Ground Plane

After a detailed study, we consider the metallic ground plane among the parameters that have a big influence on the response. The same issues and other parametric study will be discussed in the next subsections in detail. in Fig. 2 we plot the return loss response for different dimensions of the metallic ground plane. We conclude that the dimension of the ground plane have a big effect on the

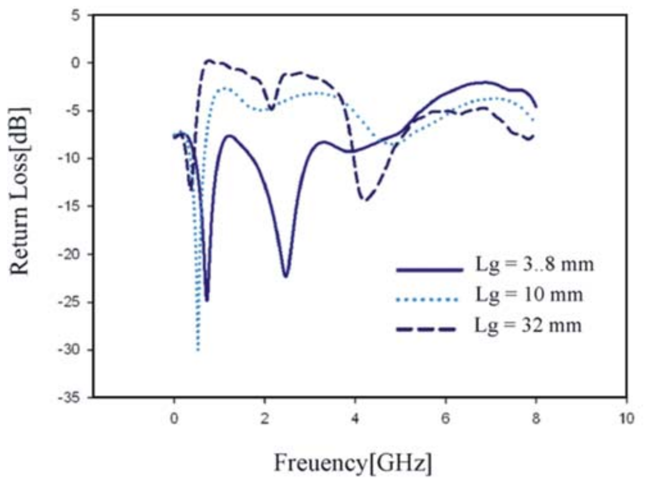


Fig. 2. Return loss for different ground plane length values (L_g).

bandwidth. It can be seen that this geometry can operate for several technologies making it suitable for wide band applications. Note that, the optimized value of the partial ground plane length of 3.8 mm will be maintained for the rest of this work.

B. Effect of the Thickness of the Upper Substrate

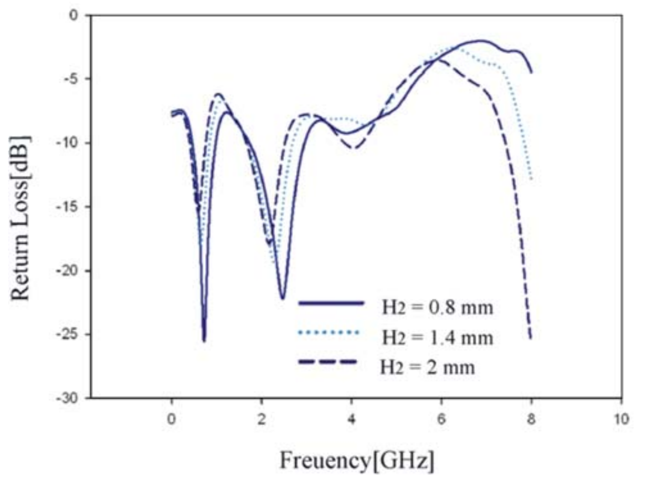


Fig. 3. Return Loss for different thickness of the upper substrate study.

The return loss of the proposed UWB antenna for different values of H_2 is presented in Fig. 3. It can be shown that the thickness of the upper substrate has an important effect on the impedance bandwidth and the central frequencies are shifted toward the low frequencies. It's observed also when the thickness of the upper substrate value increases, the frequency bands disappears. That is way the optimized dimension of the thickness for the best response takes H_2 = 0.8 mm value. Fig. 4 show the Return Loss characteristic for different dielectric permittivity

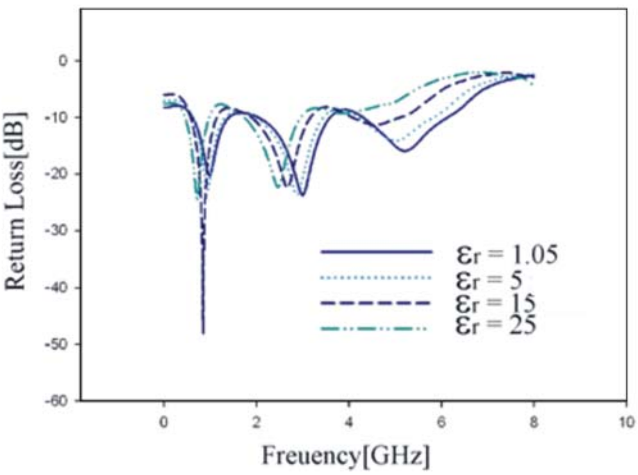
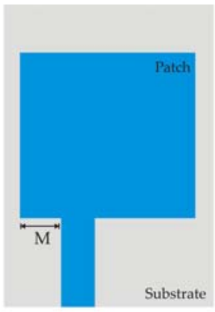


Fig. 4. Return loss for different value of dielectric permittivity of the upper substrate.

values. It is clearly shown that the frequency bands are shifted and a new ultra wide band of 5.8 GHz was appeared for $\varepsilon_r = 1.05$.

C. Effect of the Feed Line Position

In this section, the effect of the feed line position on the reflection coefficient is investigated. As can be seen in Fig. 5, the effect of the parameter M on reflection coefficient is



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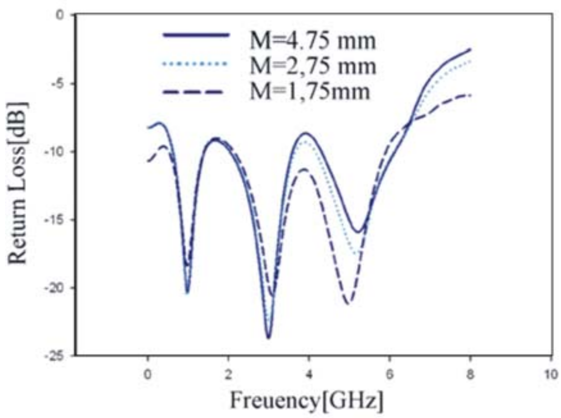

-b-

Fig. 5. –a- Antenne avec une alimentation décalée under study. –b- Return loss for different position of the feed line position from the ground plane edge.

very important. Therefore, the bandwidth is highly influenced by the position of the feed line from the ground plane edge. It is observed that the optimum value of M is 2.75 mm. For brevity, It should be noted that the effect of the feed line position due to surface current density of the antenna. Consequently, the antenna under study could be used for several recent technologies as GSM, DCS1800, PCS1900, UMTS, ISM Band, WiFi, WLAN, WiMAX Bluetooth and GPS…etc.

3 Compact U-Shaped Antenna Design

A. Aperture Effects

In this section, some modifications for the designed antenna are presented. Particularly, our investigation has been focused on the effect of the radiating element geometry on the behavior of the results. As it is clear from Fig. 6, the shape of the antenna radiating elements geometry

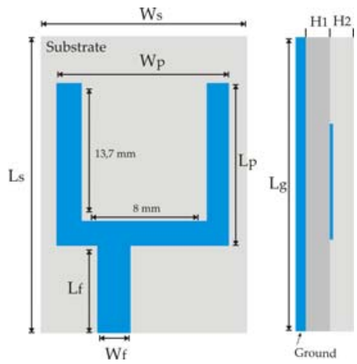

Fig. 6. Geometry of the optimal design of the compact proposed U-shaped antenna.

underwent some modifications. We then demonstrate that this modification in the design of the radiating element has a double effect, on the one hand giving rise to a

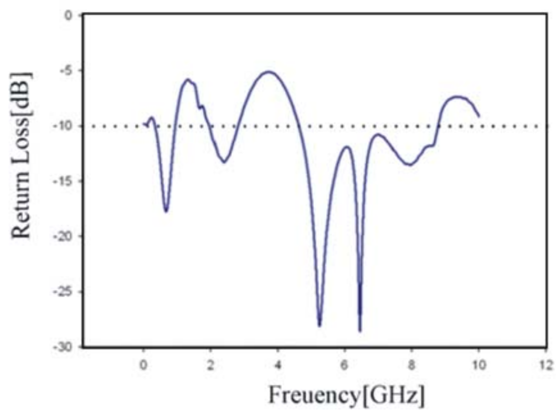

Fig. 7. Return loss for different value of dielectric permittivity of the upper substrate.

new resonant frequencies apparition and on the other hand on the miniaturization of the whole antenna size. After a rigorous study of the new proposed structure with the slot in the upper radiated element, It is verified that the best responses are obtained with the following optimized parameters of the new proposed u-shaped antenna: W_p = 10 mm, L_p = 15.7 mm, H_1 = 3.5 mm, H_2 = 0.1 mm, L_s = 25 mm, W_s = 13 mm, W_f =2.5 mm, L_f =7.8 mm, L_g = 6.5 mm. The dielectric permittivity of the upper substrate and M parameter are 25 and 3.55 respectively. The optimized size of the rectangular slot is 13.7 mm x 8 mm. Since the new parameters of the designed antenna, we prove that the implementation of an aperture in the radiated element affects in a clear way the size of the whole antenna. In other words, we conclude that the introduction of the slot on the upper patch permits the miniaturization of the antenna.

Fig. 7 shows the simulated return loss of the novel U-shaped antenna of Fig. 6. It is found that the introduction of the slot on the radiating element gives also rise to a new bandwidth of S11<-10dB, for 0.35 to 1.23 GHz, 2 to 2.9 GHz, and 4.4 to 8.9 GHz respectively, which are sufficient to satisfy our design goals. In this way, the novel Tri-band rectangular U-shaped patch antenna design can surely operate for all the following bandwidth technologies: GSM, Wi-Fi, Bluetooth, wireless local area network (WLANs) applications operating for 5-6 GHz ISM band, WiMax and GPs. It should be noted that, wideband applications could be also considered.

B. Radiation Pattern

The simulated normalized radiation pattern of the antenna in both E-plane and H-plane are displayed in Fig. 8. The antenna shows a quiet stable radiation pattern over the entire frequency range of interest.

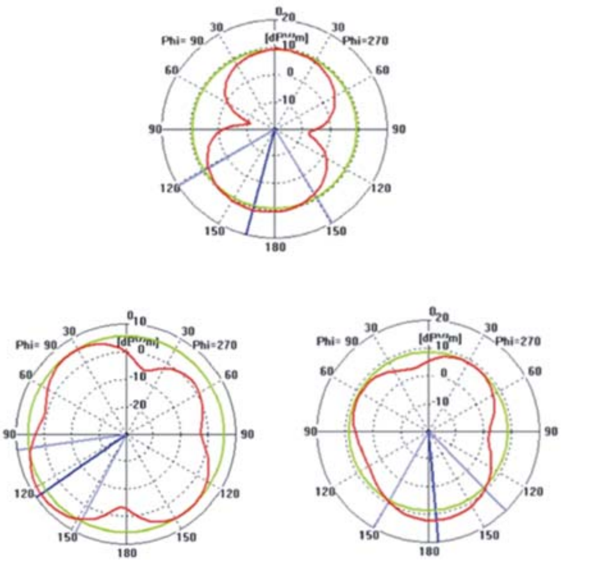

Fig. 8. Radiation patterns of proposed antenna at 2.4 GHz, 5.8 GHz and 6.5 GHz for the proposed compact U-shaped antenna.

Omnidirectional characteristics and radiation bandwidth can further be improved by using multilayer substrate or a substrate with high dielectric constant [13]. The proposed antenna has omnidirectional radiation characteristic in the H plane and nearly of eight radiation pattern in the E plane over the desired band.

C. current Surface Distributions

Figure 9 shows the simulated surface current distributions at different frequencies. At 2.4 GHz, the current mainly flows in the patch as shown in Figure 9. There is little current in the radiating patch and therefore the radiation is not considerable [12]. The ground plane has considerable surface current which causes the antenna might not be the best responsive at that frequency. At 6.5 GHz, the surface current is concentrated around the U-shaped slots as shown in Figure 10. There is considerable current flowing through the radiating patch it, which causes the antenna to be very responsive at that frequency. Thus, the impedance of the structure is well-matched and caused small reflections, which in turn result in increase in radiation efficiency, and decreases in return loss. Further missing interference between radiating patch and ground plane excited surface currents results in increase in antenna efficiency.

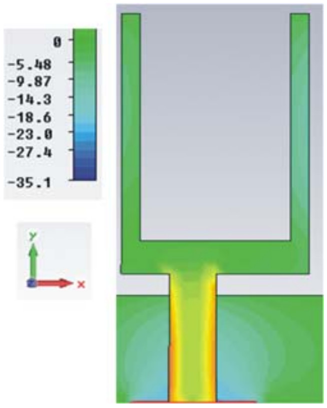

Fig. 9. Surface current distribution of proposed Tri-band U-shape UWB antenna at 2.4 GHz.

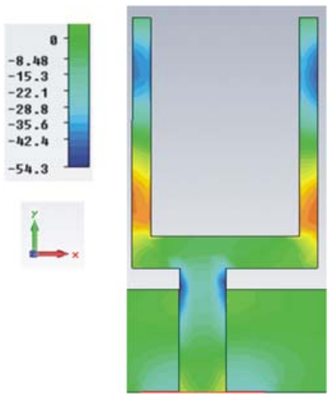

Fig. 10. Surface current distribution of proposed Tri-band U-shape UWB antenna at 6.5 GHz.

4 CONCLUSION

The design of a new compact low cost printed multilayer high permittivity U-shaped patch antenna has been presented and discussed. The proposed antenna can be easily integrated within the PCBs of various systems. By simply adjusting the U-shaped slot in the radiating plane and the length of the ground plane, the desired frequency band and the size of the antenna can be successively controlled. Several geometry parameters have been proposed and investigated in details with the objective to shift the bandwidth and adapt the antenna to operate for various technologies as GSM, Wi-Fi, Bluetooth, wireless local area network (WLANs) applications operating for 5-6 GHz ISM band, WiMax, GPs and wideband applications. As can be seen, the radiation patterns are omnidirectional over the desired frequency bands and the analysis results of the Return Loss simulations shows that the proposed U-shaped planar antenna can be widely used in recent of telecommunication systems.

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